P R O J E C T   S U B M I C H

A Report and Appraisal of the Use of a
Research Submarine in the Great Lakes

by the

Great Lakes Research Division
The University of Michigan

Special Report No. 33
Great Lakes Research Division
The University of Michigan
Ann Arbor, Michigan
1968

TABLE OF CONTENTS

INTRODUCTION

The Great Lakes Research Division first became seriously interested in exploring the applicability of a research submarine to Great Lakes investigations in May 1964. Our general ideas were first discussed with Allyn C. Vine, after whom the Woods Hole Oceanographic Institution's deep submergence research vehicle, "Alvin," was named. In October 1964 Mr. Vine spent a day at Ann Arbor discussing with us the capabilities of various existing research submarines and those seemingly best suited to Great Lakes studies. Following his advice we contacted several companies engaged in the manufacture and lease of submersibles and made arrangements for a representative from the following companies to come to Ann Arbor:

1. Navigation Systems Division of Autonetics, North American Aviation Inc. January 1965.
2. Underseas Division, Westinghouse Electric Corporation. February 1965 and January 1966.
3. Rebikoff Oceanics Inc. March 1965.
4. Electric Boat Division, General Dynamics Corporation. March 1966.

Following the Westinghouse presentation in February 1965, Jack Hough, Clifford Tetzloff and David Chandler, all staff members of the Great Lakes Research Division, flew to San Diego, California, and spent three days aboard the Westinghouse ship "Burch Tide" observing the procedure involved in using Cousteau's Diving Saucer. Also, while in San Diego a visit was made to Scripps Institution of Oceanography, discussing with Drs. Fred N. Spiess and Francis P. Shepard their experiences in the use of the research submarine and their evaluation of its suitability for Great Lakes studies.

In May 1966, after a careful evaluation of the information gained from contacting organizations and individuals with experience in the operational and scientific use of research submarines, the University of Michigan asked both Westinghouse Electric Corporation and General Dynamics to furnish a firm price quotation for the lease of their research submarine for a period of two weeks in the summer of 1967. A contract was signed with General Dynamics in May 1967 for the lease of STAR II for a period of two weeks in late June.

The contract did not include the services of a support ship. Anticipating this the University had made arrangement with the U. S. Coast Guard for use of the cutter WOODBINE for this purpose. The WOODBINE (USCG Cutter WLB-289) is 180 feet long, has a 37-foot beam, is of about 935 tons displacement, cruises at 14 mph, has a large waist-deck work area, and is equipped with a buoy-tending crane of over 10-tons capacity. Her officers and crew are experienced in the handling of heavy weights at sea. The ship's performance was highly satisfactory in every respect.

Financing of the Submich operation was with funds from the Institute of Science and Technology of the University of Michigan. Major responsibility for the operation was assumed by Charles F. Powers who managed the operation, and Clifford Tetzloff who acted as field coordinator.

THE STAR II

STAR II is a two-man submarine designed for underwater research and engineering on the continental shelf. The bow of the vessel is a pressure-sphere of steel about five feet in internal diameter. The sphere receives two persons, a seated pilot and an observer lying on the bottom. Six through-hull viewports provide visibility for the pilot and observer. Navigation is by magnetic compass, depth gage, fathometer, and voice communication to a tender on the surface.

Externally attached to the front of the pressure sphere were a television camera and lights, a still camera with strobe flash, a remote-control mechanical arm operated from inside, and a metal basket for holding samples collected by the arm.

Most of the length of the vessel consists of hydrodynamic fairing within which are located batteries, ballast tanks, buoyancy materials, and ancillary operating gear.

Propulsion and maneuvering power is provided by two reversible motors on the horizontal elevators of the tail and a vertical reversible motor in the sail atop the hull.

The primary specifications of STAR II are:

Length: 17.7 feet
Weight: 4.7 tons
Submerged endurance: 8 hours
Payload: 250 pounds
Range: 12 miles
Maximum speed: 3 knots
Life support: 48 man-hours
Operating depth: 1200 feet

The STAR II being launched.

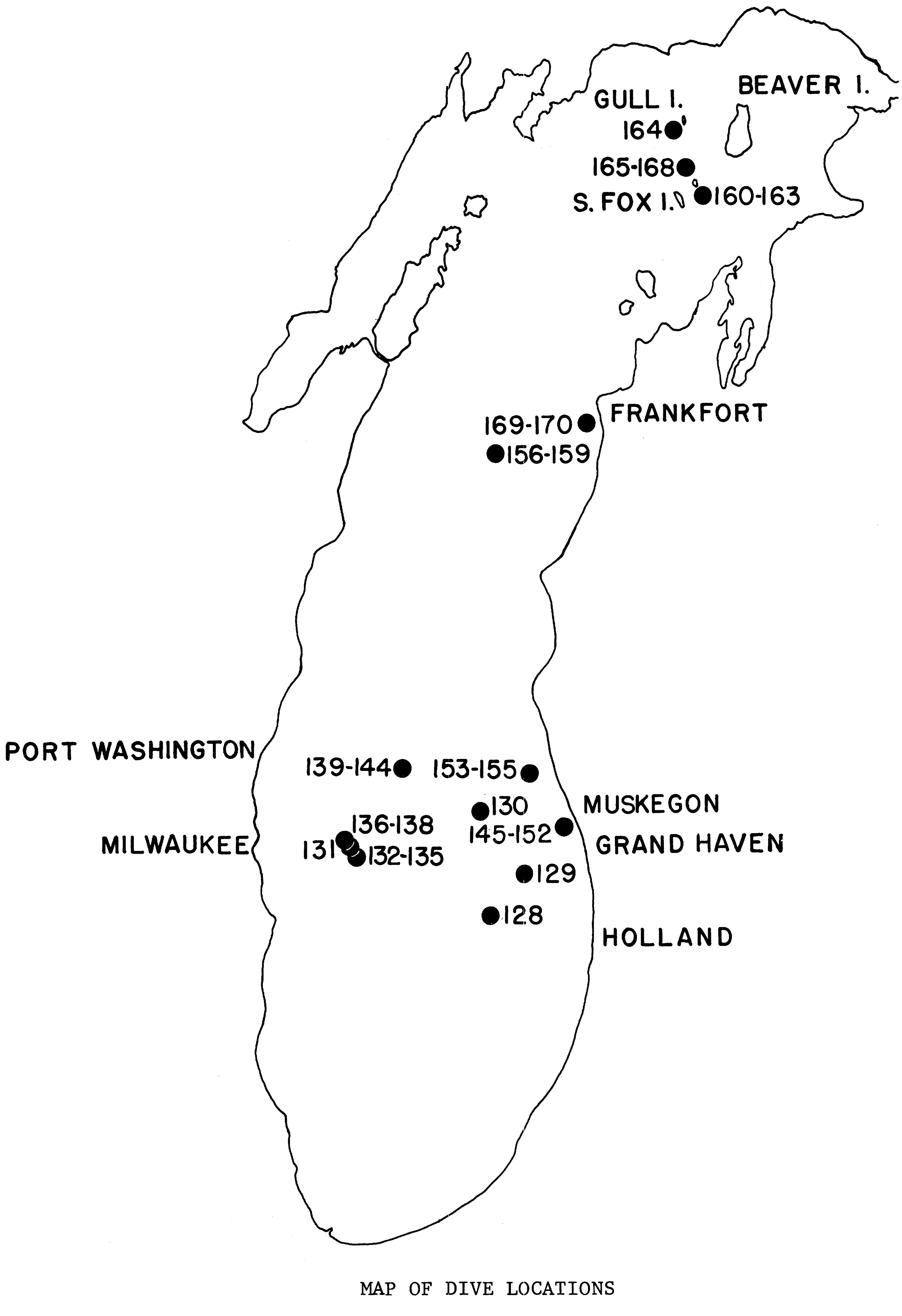
The U.S. Coast Guard Cutter WOODBINE with the STAR II on deck.

OBJECTIVES OF THE OPERATION

The primary objective of Project Submich was to determine the feasibility and applicability of using a small research submarine in the conduct of Great Lakes research. Specific problems in biology and geology received major attention since they seemed best suited to methods of direct observation and photography, and also because extensive sampling from surface vessels had provided a background of conventionally obtained information which could be checked by the submersible's observations.

It was also hoped that experience with a submarine would result in ideas and suggestions for improved instrumentation (for both submersibles and surface ships) to be applied to quantitative sampling of the environment.

Deliberate effort was made to provide diving opportunities to as many staff scientists as possible, in order to obtain the greatest breadth of assessment of the submersible. Fourteen dives were made by senior scientists of the Division and six by qualified graduate student research assistants. In addition, six dives were made by other University faculty members whose interests dovetailed with ours and whose opinions were of value in our assessment of the submarine as a research facility.



MAP OF DIVE LOCATIONS

DIVING LOG

A chronological log of operations is given here. Summaries of dive locations, depths, diving time, visibility, and personnel involved, follow as Tables 1, 2, and 3. Dive numbers are those assigned by General Dynamics Electric Boat Division.

June 14, 1967, Wednesday: Truck carrying STAR II and support van arrived at Grand Haven in early evening. (Parked on grounds of State Police Post overnight.)

June 15, Thursday: STAR II and support van loaded on deck of WOODBINE at Escanaba Park dock in the morning. Dry launch and retrieval practiced by WOODBINE deck crew at dock. Checkout of STAR II gear and equipment and preparation for diving carried on all day, and far into the night.

June 16, Friday: Continued checkout and preparation for diving. A trim dive was made in the Grand River with satisfactory results.

June 17, Saturday: WOODBINE departed dock at 0700. Dive No. 128 was made at about 1000. Fog patches made diving conditions marginal, and prevented diving during much of the day. Dive No. 129 was made at about 1800. Bottom visibility was zero on both dives. The mechanical arm was removed from STAR II for Dive No. 129 to permit closer approach to bottom (viewport about one foot off bottom) but bottom was still not visible. Returned to Grand Haven for the night.

June 18, Sunday: WOODBINE in Grand Haven - day off.

June 19, Monday: WOODBINE departed Grand Haven at 0700. Dives Nos. 130 and 131 made. Moored at Coast Guard Base, Milwaukee.

June 20, Tuesday: Underway from Milwaukee at 0700. Diving operations conducted from 1020 to 1800 in area of geological interest 25 miles ENE from Milwaukee. Bottom visibility fair to good. Completed Dives Nos. 132-135. One rock picked off bottom. Returned to Milwaukee Coast Guard Base about 2100.

June 21, Wednesday: Underway from Milwaukee at 0700. Dives Nos. 136-138 completed in same general area as previous day. Three small rocks picked off bottom. Returned to Milwaukee Coast Guard Base about 2000.

June 22, Thursday: Underway from Milwaukee at 0600. Diving operations conducted on the mid-lake high about 40 miles N.E. from Milwaukee. Several rock samples picked off the bottom here. WOODBINE moored at Grand Haven for the night. Dives Nos. 139-144 completed.

June 23, Friday: Press Day. Dives Nos. 145-152 completed near weather tower off Muskegon.

June 24, Saturday: Underway from Grand Haven at 0800. Dives Nos. 153-155 made off White Lake. WOODBINE moored at Grand Haven about 1700.

June 25, Sunday: WOODBINE at dock in Grand Haven until 2300, then underway for deep area of Lake Michigan, off Frankfort.

June 26, Monday: WOODBINE on station for diving about 0700 with depth of 912 ft indicated on WOODBINE sounder. Completed Dives Nos. 156-159. Water temperature 39°F from surface to bottom. Moored at Frankfort about 1730.

June 27, Tuesday: Underway from Frankfort at 0700 to diving area just off S.E. corner of South Fox Island. Dives Nos. 160-163 made here. WOODBINE moored at Charlevoix for the night.

June 28, Wednesday: Underway from Charlevoix at 0700. Dives Nos. 164-168 made in area north of North Fox Island and near Richards Reef. Bottom visibility was zero at depths between 300 and 500 ft except Dive No. 167, on bottom at 420 ft, had good visibility. Other dives in the same location, both deeper and shallower, reported zero visibility. Anchored in St. James Harbor, Beaver Island, overnight.

June 29, Thursday: Underway at 0600 for dive location at Frankfort. Dense fog prevented diving during most of day. Fog lifted briefly at about 1700 while WOODBINE was hoveto near shore S.W. from Frankfort and Dives Nos. 169-170 completed. Dense fog rolled in during Dive 170 and terminated diving for the day. Moored at Frankfort overnight.

June 30, Friday: Underway at 0600 for deep area off Frankfort. Dense fog prevented diving and WOODBINE headed for Grand Haven, arriving about 1800. Unloading of STAR II and support van onto truck began as soon as WOODBINE moored, and completed around 2100. University of Michigan crew departed for Ann Arbor about 2200.

Table 1

STAR II DIVES LAKE MICHIGAN 1967

Gen. Dyn. Elec. Bt. Div. Dive No.	Date	Location N. Lat.	W. Long.	Passenger	Depth* Feet	Remarks
127	6-16-67	Grand River	Grand Haven	Mr. M. Ida	25'	Trim Dive
128	6-17-67	42-48-50	86-41-30	Dr. C. F. Powers	295'	Biology
129	6-17-67	42-58-00	86-32-10	Dr. D. C. Chandler	285'	Biology
130	6-19-67	43-12-00	86-45-00	Dr. J. L. Hough	340'	Geology
131	6-19-67	43-03-00	87-23-00	Dr. J. L. Hough	220'	Geology
132	6-20-67	43-01-00	87-21-00	Mr. Lee Somers	260'	Geology
133	6-20-67	43-01-00	87-21-00	Dr. J. C. Ayers	260'	Biology
134	6-20-67	43-01-00	87-21-00	Mr. R. Anderson	270'	Biology
135	6-20-67	43-01-00	87-21-00	Mr. C. Tetzloff	270'	Biology
136	6-21-67	43-03-50	87-25-00	Dr. J. L. Hough	275'	Geology
137	6-21-67	43-03-50	87-25-00	Mr. D. Brandon	275'	Geology
138	6-21-67	43-03-50	87-25-00	Dr. J. C. Ayers	240'	Topography
139	6-22-67	43-20-30	87-09-00	Dr. J. L. Hough	140'	Geology
140	6-22-67	43-20-30	87-09-00	Dr. C. F. Powers	145'	Biology
141	6-22-67	43-20-30	87-09-00	Mr. Paul Josephson	140'	Geology
142	6-22-67	43-20-30	87-09-00	Mr. J. Worth	140'	Geology
143	6-22-67	43-20-30	87-09-00	Lt. J. E. Margeson	140'	Orientation
144	6-22-67	43-20-30	87-09-00	Dr. D. C. Chandler	135'	Biology
145	6-23-67	43-09-30	86-19-06	Radm. C. Tighe	35'	PR Day
146	6-23-67	43-09-30	86-19-06	Capt. R. G. Parks	35'	PR Day
147	6-23-67	43-09-30	86-19-06	Mr. G. Fulk	35'	PR Day
148	6-23-67	43-09-30	86-19-06	Dr. G. Van Wylen	35'	PR Day
149	6-23-67	43-09-30	86-19-06	Dr. G. Norman	35'	PR Day
150	6-23-67	43-09-30	86-19-06	Dr. J. T. Wilson	35'	PR Day
151	6-23-67	43-09-30	86-19-06	Dr. J. Zumberge	50'	PR Day
152	6-23-67	43-09-30	86-19-06	Dr. G. Cooper	50'	PR Day
153	6-24-67	43-20-30	86-31-00	Prof. R. Yagle	230'	Orientation
154	6-24-67	43-20-30	86-31-00	Capt. R. L. Thibault	230'	Orientation
155	6-24-67	43-20-30	86-31-00	Capt. D. Haig	230'	Orientation
156	6-26-67	44-28-30	86-43-00	Dr. A. Robertson	840'	Biology
157	6-26-67	44-28-30	86-43-00	Dr. C. F. Powers	840'	Biology
158	6-26-67	44-28-30	86-43-00	Mr. R. Anderson	840'	Biology
159	6-26-67	44-28-30	86-43-00	Mr. L. Somers	845'	Geology
160	6-27-67	45-24-30	85-40-50	Dr. J. L. Hough	160'	Geology
161	6-27-67	45-24-30	85-40-50	Mr. R. DiGiovanni	100'	Geology
162	6-27-67	45-24-30	85-40-50	Dr. A. Robertson	100'	Biology
163	6-27-67	45-24-30	85-40-50	En2 J. L. Schaumleffel	100'	Orientation
164	6-28-67	45-39-45	85-48-00	Mr. C. Tetzloff	285'	Biology
165	6-28-67	45-31-30	85-46-30	Mr. L. Somers	470'	Geology
166	6-28-67	45-31-30	85-46-30	Mr. R. Anderson	460'	Biology
167	6-28-67	45-31-30	85-46-30	Chbosn R. E. Behrens	420'	Orientation
168	6-28-67	45-31-30	85-46-30	Mr. L. M. Fead	345'	Qualification
169	6-29-67	44-36-50	86-17-20	Dr. J. T. Wilson	300'	Geophysical
170	6-29-67	44-36-50	86-17-20	Mr. William Stephens	300'	Orientation

* Depth in feet, as indicated on STAR II depth gauge. No correction for temp. or salinity.

Table 2

STAR II OPERATIONS

Summary of Diving Time and Visibility Conditions

Date	Electric Boat Division Dive No.	Submerged Time Hrs. - Min.	Bottom Visibility: Bottom Visible	Bottom Visibility: Bottom Not Visible	Passenger
6-16-67	127	0 - 30		X	M. Ida
6-17-67	128	1 - 07		X	C. F. Powers
	129	1 - 00		X	D. C. Chandler
6-19-67	130	1 - 05		X	J. L. Hough
	131	1 - 00	X		J. L. Hough
6-20-67	132	2 - 14	X		Lee Somers
	133	1 - 10	X		J. C. Ayers
	134	1 - 00	X		R. Anderson
	135	1 - 00	X		C. Tetzloff
6-21-67	136	2 - 30	X		J. L. Hough
	137	1 - 45	X		D. Brandon
	138	0 - 55	X		J. C. Ayers
6-22-67	139	1 - 10	X		J. L. Hough
	140	1 - 20	X		C. F. Powers
	141	0 - 35	X		P. Josephson
	142	0 - 35	X		J. Worth
	143	0 - 30	X		Lt. J. E. Margeson
	144	0 - 30	X		D. C. Chandler
6-23-67	145	0 - 40		X	Radm. C. Tighe
	146	0 - 35		X	Capt. R. G. Parks
	147	0 - 45		X	G. Fulk
	148	0 - 35		X	G. Van Wylen
	149	0 - 30		X	A. G. Norman
	150	0 - 23		X	J. T. Wilson
	151	0 - 35		X	J. Zumberge
	152	0 - 25		X	G. Cooper
6-24-67	153	1 - 00		X	R. Yagle
	154	0 - 34		X	R. L. Thibault
	155	0 - 35		X	D. Haig
6-26-67	156	1 - 32	X		A. Robertson
	157	2 - 00	X		C. F. Powers
	158	1 - 14	X		R. Anderson
	159	1 - 25	X		Lee Somers

Summary of Diving Time and Visibility Conditions (cont.)

Date	Electric Boat Division Dive No.	Submerged Time Hrs. - Min.	Bottom Visibility: Bottom Visible	Bottom Visibility: Bottom Not Visible	Passenger
6-27-67	160	2 - 00	X		J. L. Hough
	161	0 - 29	X		R. DiGiovanni
	162	1 - 00	X		A. Robertson
	163	0 - 30	X		En2 J. L. Schaumleffel
6-28-67	164	0 - 37		X	C. Tetzloff
	165	0 - 50		X	L. Somers
	166	1 - 10		X	R. Anderson
	167	1 - 05	X		Chbosn R. E. Behrens
	168	0 - 30		X	L. M. Fead
6-29-67	169	0 - 40	X		J. T. Wilson
	170	0 - 35	X		W. Stephens
			25	19	29

Total number of dives: 44
Number of dive days: 12
Total time submerged: 42 hrs. - 10 min.
Average time submerged/dive: 0 hrs. - 58 min.
Bottom visible before contact, No. of dives: 25
Bottom not visible before contact: 19 dives
No. of passengers making one or more dives: 29

Table 3

PASSENGERS ON USCGC <u>WOODBINE</u> DURING <u>STAR II</u> OPERATIONS
(excluding press day)

Name	Affiliation	June 1967														
		16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Robert Anderson	Univ. of Mich.	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
John C. Ayers	" " "				x	x	x									
Dale Brandon	" " "				x	x	x	x								
Christopher Carey	" " "	x	x											x	x	
David C. Chandler	" " "		x				x	x								
Gerald Davenport	" " "															
Donald Haig	" " "									x						
Jack L Hough	" " "				x	x	x	x	x	x	x	x	x			
Paul Josephson	" " "				x	x	x	x								
Jay Katz	" " "		x				x	x	x							
William LaCrosse	" " "	x	x													
Finn Michelsen	" " "													x	x	
Charles F. Powers	" " "						x	x			x					
Andrew Robertson	" " "		x								x	x	x			
Lee Somers	" " "	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Clifford Tetzloff	" " "	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Richard L. Thibault	" " "									x						
James T. Wilson	" " "													x	x	
Raymond Yagle	" " "									x						
James Worth	Triangle Res. Inst.						x	x	x							
Lou Fead	Elec. Boat	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Al Rutherford	" "	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Bob Hill	" "	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Mike Ida	" "	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Stephen Schneider	Gr. Lakes Found.										x					
Richard DiGiovanni	Univ. of Mich.												x			
Lare Wardrop	WWJ-TV		x													
John Carlson	WWJ-TV		x													
Seeman Mandel	CBS-NEWS				x											
Isadore Blackman	CBS-NEWS				x											
Edwin Hogan	CBS-NEWS				x											
Luigi Mendicino	Chicago Trib.				x											
James L. Yuenger	" "				x											
Ens. Bonnebaker	USCG HQ			x	x	x										
S. A. Wilk	Milw. Sentinel					x										
Fred Tonne	Milw. Journal					x										
Harry Pease	" "					x										
Marshall Savick	WTMJ-TV					x										
Jon Esther	WISN-TV					x										
James Vogt	WISN-TV					x										
Robert Brice	WLUK-TV						x									
Jerry Horen	WLUK-TV						x									
E. W. Dery	Technician C.G., 9th Dist.						x	x	x							
Lt. J. T. Leigh	C.G., HQ							x								
Charles L. Scott	Chi. Daily News							x								
Robert L. Worden	" " "							x								
Boyce Rensberger	Detr. Free Press							x								
John F. Jaqua	Chi. Daily News							x								
Ens. Frey	C.G., HQ										x					
W. M. Stevens	Oceanology Mag.													x	x	
D. M. Graham	Oceanology Mag.													x	x	

REPRESENTATIVE DIVES

A number of dives are presented here as representative of Operation Submich, the situations encountered, and the observations and data obtained. Their locations extend from the southernmost to the northernmost boundaries of the study region, and the geographical situations include the flat plain region off Holland, the region of bedrock outcrop off Milwaukee, the mid-lake high, the deepest part of the lake off Frankfort, and the extreme north end near Beaver Island. Depths given here have been corrected for fresh water, whereas those in Table 1 are as read directly from the depth gage which was calibrated for sea water.

Area: In eastern half of lake between Grand Haven and Holland.

Dive numbers: 128, 129.

Depths: 303, 291 ft.

Observers: C. F. Powers, D. C. Chandler.

Purpose of dives: To compare visually the benthic environments in regions of different sediment types.

Results:

Visibility: 2 ft.

Penetration of visible ambient light: 200-250 ft.

Nature of bottom: Bottom was not visible. There appeared to be a very turbid stratum of water, about one foot thick, at the sediment-water interface.

Currents: A near-bottom easterly current estimated at several cm/sec was observed on both dives.

Biota: Numerous amphipods were seen swimming above bottom during both dives. There were definite indications that they were attracted by the floodlights. On Dive 128 a rather dense layer of large copepods was encountered about ten feet from bottom.

****

Area: West half of lake about 25 miles ENE from Milwaukee.

Dive number: 132.

Depth: 246-267 ft.

Observer: Somers.

Purpose of dive: Geological observation in a region characterized by bedrock outcroppings.

Results:

Visibility: 4 ft.

Penetration of visible ambient light: Not noted.

Nature of bottom: Bedrock covered with silt and particulate matter to depths of one-half inch. Some bedding plane structure observed. Erratic cobbles and boulders. Bottom sloped gently from 240 ft down to 260 ft. No steep slopes or escarpments were seen.

Currents: Not noted.

Biota: No benthic fauna seen.

****

Area: West half of lake about 25 miles ENE from Milwaukee.

Dive number: 133.

Depth: 267 ft.

Observer: Ayers.

Purpose of dive: Geological and biological exploration in region of bedrock outcroppings.

Results:

Visibility: 1 ft.

Penetration of visible ambient light: Not noted.

Nature of bottom: Soft red-brown silty clay with complete lack of topography.

Currents: Not noted.

Biota: No benthic fauna seen. Zooplankton occasionally observed in the water column.

****

Area: West half of lake about 25 miles ENE from Milwaukee.

Dive number: 135.

Depth: 277 ft.

Observer: Tetzloff.

Purpose of dive: Biological observation in a region characterized by bedrock outcroppings.

Results:

Visibility: Several feet.

Penetration of visible ambient light: Not noted.

Nature of bottom: Although immediately previous dives had encountered rocky bottom, on this dive bottom was flat featureless firm clay lacking any relief or contrast.

Currents: None.

Biota: No benthic fauna seen. A few zooplankters detected in the water column.

****

Area: West half of lake off Milwaukee.

Dive number: 138.

Depth: 289 ft.

Observer: Ayers

Purpose of dive: Geological and biological exploration in region of bedrock outcroppings.

Results:

Visibility: 12 ft.

Penetration of visible ambient light: Not noted.

Nature of bottom: From a large field of small boulders a gigantic staircase of bedrock slabs sloped downward from 185 to 289 ft, at an angle of about 35 degrees. It appeared to be limestone. Occasional small rounded boulders lay on the slabs. All horizontal surfaces were covered by about one-half inch of fluffy brown material.

Currents: Not noted.

Biota: Mysids, amphipods, crayfish, and sculpins were seen in the fluffy surficial material. The biota was not rich. The most numerous organisms appeared to be the crayfish. One pelagic fish, either a chub or an alewife, was seen swimming about a foot off bottom.

A detailed account of the geological observations made during Dives 133 and 138 appears as Part 1 of the Appendix.

****

Area: Trans-lake ridge between Milwaukee and Muskegon.

Dive numbers: 140, 144.

Depths: 145, 135 ft.

Observers: Powers, Chandler.

Purpose of dives: To observe the biota and environmental characteristics of the shallowest, mid-lake portion of the trans-lake ridge.

Results:

Visibility: 8-10 ft.

Penetration of visible ambient light: To bottom. Major topographic features were visible.

Nature of bottom: Hard clay with sand patches; rocky areas of flattened cobbles, boulders up to 7 feet in diameter. The bottom was highly irregular, with large depressions 20 feet and greater across into which the submarine descended.

Currents: A near-bottom current of about 5-10 cm/sec was observed moving from the northeast.

Biota: Mysids and sculpins were seen over all types of bottom. Mysids were observed to orient into the current, similar to a school of fish, and appeared to maintain position by clinging to bottom and by swimming.

****

Area: East half of lake about 25 miles SSW of Frankfort, in deepest part of lake.

Dive numbers: 156, 157, 158, 159.

Depth: 860 ft.

Observers: Robertson, Powers, Anderson, Somers.

Purpose of dive: Biological and geological observation in the deepest known part of Lake Michigan.

Results:

Visibility: 8-10 ft.

Penetration of visible ambient light: 400-450 ft.

Nature of bottom: A gently undulating nearly flat plain heavily interspersed with elongate depressions up to about one foot long and several inches deep. The sediment type was a very fine, easily dispersed silt or clayey silt.

Currents: No current could be detected at the bottom.

Biota: Robertson, Powers, and Anderson were biological observers, while Somers was interested primarily in the geology of the region. The three biologists were able to obtain a series of unique observations of the vertical distribution of the mysids occurring in the deepest part of the lake, and a detailed account of these observations is included here.

A detailed account of the observations made by the three biologists during Dives 156, 157, and 158 appears as Part 2 of the Appendix.

****

Area: North end of lake about 12 miles west from Beaver Island light.

Dive number: 164.

Depth: 292 ft.

Observer: Tetzloff.

Purpose of dive: Biological observation in a region believed to contain large numbers of crayfish.

Results:

Visibility: One foot.

Penetration of visible ambient light: Not noted.

Nature of bottom: Gray-brown sandy clay. Restricted visibility did not permit observations of topographic features.

Currents: None.

Biota: No benthic fauna visible. Zooplankton seen in water column.

****

EVALUATION

General Statement

The research submarine has revolutionized the concept of underwater research and has increased the accuracy and efficiency of many measurements several fold over the conventional surface-ship methods. It eliminates the random groping method of sampling and substitutes the trained mind and eye, thus making possible accurate location of sampling sites and the immediate mental assimilation of the complex environment and the dynamic events taking place. Its value as a research tool has been clearly demonstrated for the sea, but its use in the Great Lakes has been restricted essentially to "Operation Submich," June 1967.

Evaluation of the Operational and Observational Aspects of Operation Submich

Personnel. The on-board operation of STAR II from the USCGC WOODBINE proceeded exceptionally well. LCDR. John Mitchell, C.O. of the WOODBINE, his officers, and men were outstanding in their capabilities and cooperation. The General Dynamics Electric Boat crew, under the direction of Mr. Lou Fead, were a competent and energetic group who made every effort to assure that the operation was a success. The personal and professional relationship between WOODBINE officers and crew, Electric Boat crew, and University of Michigan personnel was everything that could be desired. Everyone concerned was determined to make the operation successful.

Launching and retrieval of STAR II. The deck crew and boom operator of WOODBINE, under the direction of CHBOSN Robert Behrens, handled STAR II smoothly and exceptionally well.

Launch and retrieval of STAR II from WOODBINE could become hazardous when seas reach a 4-ft height, due to the roll of the ship and the rather long pendulum when the sub is suspended from the boom. Maximum outreach of the boom is about 8 ft from the ship's side. Four-foot seas on Lake Michigan would also cause the transfer of passengers from a small boat, to the sub, to become very hazardous.

Surface support boat. A 13-ft Boston Whaler served as the support boat for the submarine. It carried two Electric Boat personnel and communications gear for maintaining contact with the submarine and with the WOODBINE. It also served to ferry the observers between the WOODBINE and the submarine. The 13-ft Whaler was somewhat marginal for this operation; the 16-ft Whaler would be considerably better.

Equipment problems. The scientific equipment with which problems were encountered were the EG&G 35-mm camera and the mechanical arm and claw. The camera can be positioned only when the submarine is out of the water, whereas a maneuverable camera with provision for aiming would be much more satisfactory. Many of the photographs appeared overexposed; this likely is due in part to the in-line orientation of the camera and the strobe flash and in part due to reflection from the white-painted claw mechanism which very often was in the field of view. The claw should in the future be painted some darker, non-reflecting color. Also, on future operations each day's film footage should be removed from the camera to simplify labelling and identification of the photos.

The mechanical arm and claw device was a rather primitive, unsophisticated version of limited usefulness. There was no provision for either rotation or

extension-retraction of the mechanism, and it was extremely difficult to recover objects from the lake bottom.

Television recorder. The quality of the picture recorded on video tape is surprisingly good, and in the case of fish and other animals on and near bottom, the motion picture adds a quality just not present in the still photos. Video tapes from the STAR II operation have considerable noise in the picture on the playback, but at this time it is unknown whether the noise is in fact on the tape, or whether it was due to external sources in the playback mechanism or ship's power supply.

The chief disadvantage of the video tapes is that they must be played back on a Sony EV-200 Video Recorder. So far as can be determined, there is only one Sony EV-200 recorder in all of Ann Arbor. This one recorder is available from a private firm on a rental basis, and the price is relatively high.

Advantages of the Submarine as a Research Tool

In spite of a number of limitations which will subsequently be discussed, the STAR II demonstrated a definite ability to supplement and extend scientific investigations in the Great Lakes. It seems obvious that a small research submarine would be a desirable facility to have available in the Great Lakes. Such a means of first-hand exploration and observation has produced, during Operation Submich, and would continue to produce, unique and invaluable data relating to the biology and geology of the lake.

Probably the major overall contribution of the submarine during our operation in Lake Michigan was the opportunity it afforded for obtaining first-hand data with which to either substantiate or modify our pre-existing concepts of the deep environment of the lake. A number of observations were

made which significantly extended our knowledge and enhanced our appreciation of subsurface conditions. Ambient light was found to penetrate to greater depths than had formerly been suspected. Under the best conditions the greatest depth to which a Secchi disc can be seen in Lake Michigan is about 16 m. From the submarine, however, ambient light was detectable to the eye to depths of 120-130 m. At the limit of detectability, a faint greenish glow could barely be discerned when looking toward the surface. Such observations of greater than expected light penetration have also been made from submarines operating in the ocean, where light penetration to 700 m has been recorded. This greatly exceeds previously expected values.

Large quantities of particulate matter were found to exist at all depths, and in many instances seriously impeded visibility. Light from the floodlights of the submarine was back-reflected from the minute particles, creating the effect of looking through a lighted window into a snowstorm. As a consequence, this phenomenon was commonly referred to as the "marine snow." It appeared to consist largely of organic detritus, living plankton, and inorganic material, although the chief impression as it was watched through the viewport was that of amorphous, organic detrital particles. Knowledge of the snow and its detrimental effects on observation (discussed later) will result in improved observational techniques in future dives.

The ability to obtain close-up views of the lake bottom and its associated organisms allowed a check on our preconceived ideas of the nature of the bottom and the relation of the benthos to the sediments. Bottom sediments, where clearly observable, did not prove to be different than supposed. However, detailed viewing of the gently undulating plain of flocculent silt which composes the bottom in the deepest part of the lake, for example, and observation of the mysid-sculpin community associated with it, provided an

appreciation and comprehension of benthic conditions that could never be obtained in any other way. We know, for the first time, that the bottom there is covered with small craters created by the sculpins; we have seen the enormous numbers of mysids, some partially buried in the sediment, some creeping through its surface floc, and some swimming in the water just above bottom; and we have observed the curious bimodal vertical distribution of the mysids which was described earlier.

Limitations of the Submarine as a Research Tool

Limitations in the scientific usefulness of the submersible were of two kinds--those imposed by the environment and those resulting from design features of the vehicle and its equipment.

The major environmental limitation was that of restricted visibility caused by the "marine snow" which was observed to varying degrees on all dives. The density of the snow varied from one dive site to another, and on occasion was observed to vary sharply during a single dive. There was no discernible geographical trend in the relative density of the snow; heavy concentrations were found in both the southern and northern extremes of the diving area. It is believed that the position of the submarine's lights affected the amount of snow visible. When the lights were positioned above the viewports, near the top of the submarine, the greatest amount of back-reflection occurred and visibility was most severely impaired. With the lights below the level of the viewports, back-reflection occurred from a minimal quantity of snow and visibility was improved. It has been suggested that visibility would probably be further enhanced by positioning the lights farther forward, as from a boom, and to the side.

In conditions of dense snow it was difficult, and sometimes impossible, to see the lake bottom even when the vessel was resting on it. Under such conditions observation of benthic or swimming organisms was obviously extremely difficult. On the other hand, in situations where the snow was less dense, bottom could be seen when the submarine was two to six feet above bottom, and forward visibility extended eight to ten feet. Under these conditions organisms swimming just off bottom and those on bottom could be seen sufficiently well to permit sight-identifications and estimates of numbers.

Observations with underwater television have indicated that conditions of visibility are improved in the lake during the fall months. Although weather conditions could be expected to deteriorate somewhat during this period, the improved quality of the observations obtained might make feasible the selection of this season for future diving operations.

Several design features of the submarine and its equipment limited its usefulness. The shortcomings of the EG&G 35-mm camera and of the mechanical arm and claw have been discussed. The quality of the pictures was not uniformly good, and a great many were unusable for either geological or biological purposes. Rock sampling with the claw was difficult and tedious, and only small pieces, in limited quantity, could be obtained. It should be emphasized that during dives on the mid-lake ridge, in depths of about 140 ft, SCUBA divers descended to the bottom, rapidly collected numerous rocks, and made detailed observations that were not possible from the submarine. In such moderate depths SCUBA diving is probably a more efficient means of exploration, scientific observation, and collection.

The usability of the submarine was further restricted by its small size and consequent lack of work space, and by its slow speed and limited navigation capability. Because of space deficiencies, many sampling operations are

precluded; because of small size and limited payload capability, the number and kind of sensors and sampling devices which could be used are reduced. The vessel is not suitable as a primary facility for search and survey operations in waters of limited visibility. However, it would be quite valuable for observation in restricted localities which have been studied previously by other means.

APPENDIX

Part 1

An account of the observations made by John C. Ayers during Dives 133 and 138, 25 miles east-northeast of Milwaukee, Wisconsin. The observations were primarily geological in nature, but include pertinent biological data as well.

"In my opinion my first dive was beneficial in demonstrating three things: 1) the essential absence of feeling of motion during ascent and descent, 2) that visible light fades away to complete blackness, and 3) that "marine snow" can severely or completely limit the useful operation of a research submarine. I am now convinced that the blinding blizzard-like nature of the snow encountered on my first dive was, in some part, the effect of incorrectly located lights. The lights were located above the viewing ports and near the top of the pressure vessel, and as a result the snow could and did reflect to the observer's eyes the strongest emissions from the lights, leaving little receptivity in the eye for the soft earth-colored reflections from the bottom. On my second dive a light or lights had been placed beneath the pressure vessel and below the level of the viewing ports; these lights were directed outward and downward, delivering their light through a minimal quantity of snow and reflecting from the bottom a considerable quantity of earth-colored light completely adequate for visual observation, and which gave the impression that the near-bottom water was like nearly transparent, but brown, swamp-water. On other colors of bottom, the near-bottom water probably had the hue of the bottom.

On my first dive the snow appeared to be almost completely quiescent with an occasional small particle showing a jerky swimming motion (these were thought to be copepods) and a very few but easily recognizable Pontoporeia. With only the overhead lights available on this dive, I could see the bottom only after

we had run into it and the pilot had raised the tail of the submarine and lowered the viewing port to about a foot from bottom. The bottom at this site was of soft red-brown silty clay completely featureless in all other aspects.

The site for my second dive was predicated upon the supposed presence of a bedrock outcrop. Descending from the point where the previous dive had emerged, we reached bottom on a large field of small boulders and ran over it for a few minutes before coming to a drop-off with layered bedrock in 6- to 18-inch layers in place in slabs.

This bedrock drop-off turned out to be a gigantic staircase sloping downward from about 180 ft to 282 ft. It was composed of rock slabs fractured in rough rectangles (to judge by displaced portions) and to the eye somewhat like the limestone exposed in the old quarry at Petoskey. The slabbing was visually like that on the beach at South Point just south of Charlevoix except that the majority of the slab edges were about a foot thick. I have no doubt that this staircase (estimated slope 35°) of what was apparently limestone had been subject to subaerial erosion and weathering during the Chippewa low-lake stage. The "risers" of the staircase varied from about 6 inches to 18 inches and the "treads" were from a few inches to a couple of yards wide.

Occasional rounded small boulders similar to the boulder field above and occasional roughly rectangular blocks of bedrock (up to about 6 ft long by 2 ft wide by 18 inches thick) were encountered on the treads of the staircase; presumably they were roll-downs from above. The "limestone" of the staircase was apparently a finer-grained, denser, and less-visibly fossiliferous material than the Petoskey limestone.

All horizontal surfaces were covered by an estimated half-inch of a fluffy brown material easily suspended by the submarine's propeller wash and similar to that surficial material commonly found atop grab samples in other parts of the lake.

In this fluffy surficial material several Mysis were seen with their eyes erect and the top of the thorax exposed. These were all at the forward ends of groove trails and were evidently creeping. No swimming mysids were observed. Mysids were not abundant but several were seen. Occasional Pontoporeia were seen, but they were not abundant. Several sculpins were seen sitting on the surficial material; all swam before the submarine's lights came much closer than a yard. One other fish was seen swimming about a foot off bottom. Biologically this limestone staircase was not rich, but it was not devoid of inhabitants; crayfish were probably the most abundant organisms; numerous ones were definitely seen but all were sitting tight and partially hidden; many others must have been missed.

The bottom of the limestone staircase was an area of soft dark brown clayey material, very easily suspended by propeller wash, and containing numerous small boulders in various stages of emergence."

Part 2

Observations from STAR II on the vertical distribution of *Mysis relicta* in Lake Michigan made by Charles F. Powers, Andrew Robertson, and Robert Anderson.

The present account concerns dives made in the deepest part of Lake Michigan about 25 miles southwest of Frankfort, Michigan. Each of three divers made a 1-3/4 hour dive at the same station (General Dynamics Dives Nos. 156, 157, 158). Sequence of these dives was as follows:

Dive 1: Robertson. Time of dive 0748 - 0925 EST.

Dive 2: Powers. Time of dive 0950 - 1129 EST.

Dive 3: Anderson. Time of dive 1146 - 1330 EST.

Operational conditions were ideal. The day was calm, clear, and sunny, with practically no sea or swell. On the initial descent, Robertson noted numerous mysids below the 450-ft depth, and observed apparent discontinuities in their vertical distribution. During the ascent he attempted to obtain rough counts of their numbers with respect to depth by counting those seen through the forward viewport in the zone illuminated by the floodlights of the submarine. A similar procedure was followed by Powers and Anderson in the two subsequent dives. Powers was able to obtain counts on the way down, but temporary failure of the tape recording equipment negated results obtained during the ascent. Anderson succeeded in making counts both down and up.

The resulting counts, while sketchy and obviously subject to the errors inherent in attempting to enumerate small darting creatures through a small viewport from a moving submarine, are of considerable interest. They are summarized in Table 1A. Two depth columns appear in the table, one designated "uncorrected" and the second "corrected." The uncorrected depth is that which

was read directly from the depth dial on the pressure gauge in the submarine. The dial was calibrated for sea water, and hence yielded values which were less than actual depth in fresh water. The corrected depth is the depth of the submarine during the Lake Michigan dives as computed from the pressure in pounds per square inch measured by the pressure gauge.

Table 1A

Results of _Mysis relicta_ counts with respect to depth increments made from research submarine STAR II during three dives in Lake Michigan.

Depth Ft		Dive 1	Dive 2	Dive 3	
Uncorrected	Corrected	0748 EST Ascent	0950 EST Descent	1146 EST Descent	Ascent
400-450	410-461	2	0	0	0
450-500	461-512	8	2	0	2
500-550	512-563	45	11	1	Very numerous
550-600	563-614	51	45	9	Very numerous
600-650	614-666		60	30	38
650-700	666-717	132*	27	8	43
700-750	717-768		32	3	28
750-800	768-819	11	19	8	11
800-840	819-860	**	**		**

*The 650 and 700-ft levels were not recorded, but observer verifies greatest abundance between 600 and 650 ft.

**Few specimens except near and on bottom where they were too numerous to enumerate.

During the counting procedure, the rate of descent and ascent of the vehicle was about 25 ft per minute--sufficiently slow to permit reasonably valid estimates of the numbers of mysids seen. Visibility was about 8 to 10 ft, and the floodlights were turned on throughout the counting procedure. The mysids were quite visible within the illuminated field in front of the submarine, appearing white and shiny in the reflected light. Most of those observed were oriented vertically in the water, and many gave the appearance of hanging

motionless against the dark backdrop of the unlighted region beyond the field of view. Many others, however, were obviously in active swimming motion. The extent to which this activity was stimulated by the submarine is difficult to evaluate.

Although diving began at 0748 EST and terminated at 1330 EST, no difference in depth of light penetration was discernible to the three observers. In each case a very low level of ambient light could be distinguished at the 400-ft depth by looking toward the surface, but at 450 ft all apparent light had disappeared.

Striking similarities are apparent in the counts obtained on dive 1, dive 2, and the descent of dive 3. (Depths referred to here are the uncorrected depths as shown in Table 1A, since it was to these depths that the observations were referred.) Only 2 mysids were seen above 450 ft during dive 1, and none during dives 2 and 3. Rapid increases in numbers of mysids occurred below 500 ft, with maximum numbers being found in all three cases at the 600- to 650-ft level. Although depth was inadvertently not recorded during dive 1 at 650 and 700 ft, the observer confirms that he saw the largest numbers between 600 and 650 ft. A gradual tapering off in the counts is noticeable below 650 ft. This continued until near the bottom, where the numbers of mysids increased again. Most of these organisms were on the bottom itself, but some were seen swimming up to a height of 10 to 15 ft. In this bottom and near-bottom zone it was not possible to obtain numerical estimates, but the animals appeared to be at least as numerous as in the water column above. Mysids were literally "everywhere."

The counts obtained during the ascent of dive 3 are somewhat at variance with the other finds. It is possible that the observer had simply become more accustomed to conditions by the time the submarine began its ascent, since he

recorded much greater quantities of mysids at practically all depths than during the descent. However, the most obvious difference between these counts and the other three sets is the observation "very numerous" between 500 and 600 ft (cf. Table 1A). The observer reported that mysids occurred there in quantities too great to permit attempts at enumeration. They appeared to him to be particularly dense at about 520 ft. These observations would place the maximum concentration of mysids at a somewhat shallower depth than indicated by the other data.

It is obviously not possible to draw any precise conclusions regarding the vertical distribution of *Mysis* from the data presented here. This single exploratory mission, however, has shown that direct observation of these organisms is feasible, and that useful and unique data can be obtained by such means. It is evident that, on the day of observation, two distinct concentration zones of mysids existed, one about 200 to 250 ft off bottom, and the other at the bottom. Three out of four sets of observations placed the shallower concentration at a depth of 600 to 650 ft (614 to 666 ft corrected). Further, with the possible exception of the first two mysids sighted on dive 1, all were positioned below the depth at which ambient light was discernible to the eye.

Further useful information was derived from these dives with respect to the abundance of amphipods at these great depths. Grab samples taken by us over the past several years have indicated that amphipods are relatively scarce in such regions, reaching their peak abundance where depth to bottom is about 150 ft and decreasing rapidly at greater depths. This was confirmed during the time the submarine was operating on bottom, when a total of only about 20 amphipods were sighted swimming just above bottom by the three observers. Although amphipods are certainly the dominant benthic organism in more moderate depths, they are replaced by mysids in the deepest parts of the lake. Reliable

quantitative sampling of the mysid population must be developed in order to evaluate their relationship with the amphipods, particularly in terms of the relative abundance of these two groups of organisms in various depth zones in the lake.